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It has been reported that scores from a temperate environment step test describe the heat tolerance status of prior heatstroke patients (HP). This investigation evaluated the ability of this temperate environment heat tolerance test (HTT) to indicate altered heart rate (HR) and rectal temperature (Tre) responses of HP, before and after seven days of heat acclimation. It was concluded that this temperate environment heat tolerance test (HTT) was not a substitute for lengthier tests of heat tolerance conducted in hot environments, because HTT scores (at 25.8°C) did not indicate HR and Tre responses (at 40.1°C) in 33 % of heat acclimated (e.g. heat tolerant) HP. In addition, HTT scores did not validly discriminate between heat tolerant and intolerant HP.

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Evaluation of a Temperate Environment Test of Heat Tolerance in Prior Heatstroke Patients

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Running Head: Heat Tolerance Test for Prior Heatstroke Patients

[2 tables, 1 figure]

Summary

It has been reported that scores from a temperate environment step test describe the heat tolerance status of prior heatstroke patients (HP). This investigation evaluated the ability of this temperate environment heat tolerance test (HTT) to indicate altered heart rate (HR) and rectal temperature (Tre) responses of HP, before and after seven days of heat acclimation. On day 1, 10 male HP (61 $\pm$ 7 days post-heatstroke) bench stepped (30 cm high, 27 steps·min^{-1}) for 15 min (25.8^{o}C db, 16.2^{o}C wb). On days 2-8, subjects underwent heat acclimation (40.1^{o}C db, 23.8^{o}C wb; treadmill, 90min·day^{-1}). Heat acclimation resulted in significant decreases in final HR (152 $\pm$ 5 vs 130 $\pm$ 3 beats·min^{-1}, $p<.025$) and final Tre (38.62 $\pm$ 0.11 vs 38.13 $\pm$ 0.07^{o}C, $p<.01$). One HP (subject J) was defined heat intolerant, exhibiting inability to adapt to daily exercise in the heat. On day 9, HP repeated HTT, exactly as performed on day 1; mean group HTT scores did not change (day 1 = 39 $\pm$ 6, day 9 = 48 $\pm$ 6, $p>.05$). In contrast to heat acclimation data, HTT scores (score $\leq$ 30) indicated that four HP were heat intolerant on day 1 and two were heat intolerant on day 9. It was concluded that HTT was not a substitute for lengthier tests of heat tolerance conducted in hot environments, because HTT scores (at 25.8^{o}C) did not indicate HR and Tre responses (at 40.1^{o}C) in 33 % of heat acclimated (e.g. heat tolerant) HP. In addition, HTT scores did not validly discriminate between heat tolerant and intolerant HP.

Key words

body temperature, heat acclimation, heart rate, exertion

Introduction

In research published since 1943, heat tolerance tests have been designed to simulate the demands of specific environmental conditions or exercise requirements (e.g. mining, military, athletic endeavors). The advantage of such specificity is that tests which model real-world conditions are more likely to be useful in predicting heat tolerance under actual exercise-heat stress than tests which do not. The disadvantage of such specificity is that a heat tolerance test designed for one situation probably will not be useful in other situations. A recent review of heat tolerance tests (Armstrong et al. 1988) provided two relevant conclusions: (a) a wide range of environmental temperatures, clothing ensembles, and exercise modes/durations/intensities have been employed in previous studies; and (b) it is necessary to define specifically the experimental conditions under which the term heat tolerance test is applied. For example, one previous study (Shvartz 1977b) reported that a temperate environment heat tolerance test (HTT) distinguished prior heatstroke patients from healthy, normal humans, and distinguished heat acclimated individuals from those who were unacclimated. HTT involved bench stepping for 15min in a room maintained at 23°C dry bulb, 16°C wet bulb.

Interest in HTT at this laboratory originated from the consideration of four factors. First, if HTT accurately and precisely reflected changes in heat tolerance, then it could be utilized to define readiness/risk for duty in hot environments, and to assess the heat intolerance status of prior heatstroke patients (HP). Second, studies conducted by two South African research teams (Strydom et al. 1969; Wyndham 1973) indicated that heat tolerance can best be measured by exposing subjects to high thermal stress and exercise of significant duration/intensity. This work suggested that HTT might not be as valid as heat tolerance tests which involve prolonged work and hot environments. Third,

the original description of HTT (Shvartz 1977b) did not include individual pre-acclimation HTT scores, post-acclimation HTT scores, or anthropometric data, and it was not evident that HTT was sensitive enough to measure acute changes in physiological responses. Fourth, an independent evaluation of HTT was conducted in this laboratory (Armstrong et al. 1986) using 14 normal (non-HP) males. The results indicated that HTT was not a valid substitute for lengthier heat tolerance tests conducted at high ambient temperatures. However, it was recognized that HTT might have value in HP or at-risk populations, in agreement with Shvartz et al. (1977b) who reported that HTT was effective in evaluating the heat tolerance of HP.

Therefore, the current investigation was designed to independently evaluate the validity and sensitivity of HTT as a heat tolerance test for HP. HTT was performed before and after a 7-day heat acclimation protocol. Because heat acclimation results in a series of physiological changes which reduce bodily strain and improve one's ability to live and work in a climatic chamber (Bligh et al. 1973), it was hypothesized that HTT would indicate such changes, or lack of changes, in HR and Tre values of HP. Two research questions were posed in the current investigation: (a) "Did HR and Tre responses during HTT track the HR and Tre responses observed during exercise in the heat?", and (b) "Did HTT identify heat intolerant individuals correctly?"

Methods

An evaluation of HTT was conducted during winter and spring months, following the protocol of Shvartz et al. (1977a, b) with minor revisions. The 10 unacclimatized male subjects were prior heatstroke patients who had been declared clinically normal by their attending physicians. The criteria used to verify heatstroke were similar to those published by Hubbard et al. (1988): rectal temperature $\geq$ 106^{o}C, altered mental status, and elevated plasma enzymes (i.e.

creatine phosphokinase, lactic dehydrogenase, aspartate amino transferase, or alanine transferase). HP began this investigation 61 $\pm$ 7 days post-heatstroke. Prior to testing, each subject completed a treadmill cardiac stress test (Bruce protocol or equivalent) and exhibited normal 12-lead electrocardiographic

Table 1

responses. HP exhibited the physical characteristics described in Table 1. Surface area was calculated using the technique of DuBois and DuBois (1915). Percentage of body fat was estimated by using skinfold calipers and was calculated using the method of Jackson and Pollock (1985). Shvartz et al. (1977b) indicated that HTT may apply to men aged 17-35 years; the subjects in this investigation fell between the ages of 21 - 26 yr, except subject J (44 years).

In this manuscript, the term heat acclimatization refers to a series of physiological changes which (a) reduce the strain caused by heat stress in a natural climate and (b) improve one's abilities to live and work in a hot environment. The term heat acclimation involves the same physiological changes, but environmental factors are experimentally controlled in a climatic chamber (Bligh et al. 1973).

Days 1 and 9. All subjects bench stepped (30cm high, 27 steps$\cdot$min^{-1}) for 15min in a temperate environment maintained at 25.8 $\pm$ 0.4^{o}C dry bulb, 16.2 $\pm$ 0.4^{o}C wet bulb, and 0.002 $\pm$ 0.0003m$\cdot$s^{-1} air velocity. Before, and at the end of 15min of exercise, measurements of heart rate (HR) and rectal temperature (Tre) were taken. Final HR and Tre values were assigned an arbitrary score from 10 to 100, as originally described in Table 3 of Shvartz et al. (1977b). A composite score was calculated for each subject, using the following equation:

$$\text{Composite score} = \frac{\text{HR score} + \text{Tre score}}{2} \quad \text{(Eq. 1)}$$

HR was recorded using an ECG telemetry system (Hewlett Packard). Tre were recorded to the nearest 0.01°C (heat acclimation trials) and 0.1°C (HTT trials) from a rectal probe (Yellow Springs) inserted 8cm beyond the anal sphincter. On day 9, all subjects repeated procedures conducted on day 1 and subsequently performed a maximal aerobic power (VO_2max) test, using a modification of the procedure described by McArdle et al. (1973). Expired respiratory gases were sampled by a computerized (Hewlett Packard) on-line system developed in this laboratory, which included a gasmeter (Parkinson-Cowan), oxygen analyzer (Applied Electrochemistry, model SMA) and carbon dioxide analyzer (Beckman, model LB2). Gas analyzers were calibrated prior to each trial using a known gas mixture.

Days 2-8. To induce measurable changes in physiological responses to heat, seven days of heat acclimation were undertaken by all subjects. Each daily trial (days 2-8) consisted of 90min of treadmill exercise (5.6 $km \cdot h^{-1}$, 5 % grade) in an environmental chamber (40.1 $\pm$ 2.3°C dry bulb, 23.8 $\pm$ 1.4°C wet bulb, 0.002 $\pm$ 0.0003$m \cdot s^{-1}$ air velocity). Due to technical difficulties and subject factors beyond our control on day 8, some post-acclimation data are reported for day 7, while other post-acclimation data are reported for day 8 of this investigation. Daily sweat rate ($g \cdot m^{-2} \cdot h^{-1}$) was measured for the entire body by using body mass differences, corrected for water intake and urinary output, from pre- to post-trial. Sweat sensitivity was calculated as a measure of sweat rate per degree rise in Tre ($g \cdot m^{-2} \cdot h^{-1} \cdot {}^{o}C$). Sweat electrolytes were collected following heat acclimation trials on days 2, 5, and 8, using the whole body and clothing washdown technique described elsewhere (Armstrong et al. 1985), and were analyzed via flame photometry (Radiometer Copenhagen). All resting blood samples were taken from an antecubital vein (days 1, 4, 7) after a standing 20 min body fluid equilibration period in the heat, and were analyzed for

hematocrit (microhematocrit) and hemoglobin (cyanmethemoglobin technique, Hycel) in triplicate. Changes between resting (pre-exercise) plasma volume (%ΔPV) on days 2 and 8 were calculated. Statistical analysis of %ΔPV was not possible, due to the nature of the calculation derived by Dill and Costill (1974).

Statistical significance was examined by using the appropriate t-tests and ANOVA, at the 0.05 confidence level. All results were expressed as mean ($\pm$ SE). Correlation coefficients were computed for the relationships between composite scores (day 1 vs day 9) and the following subject characteristics: age, height, weight, surface area, mass-to-surface area ratio, % body fat, and VO_2max.

Results

Nine out of 10 subjects were declared heat acclimated by day 9 because the following significant changes in HR and Tre resulted from 90min heat acclimation trials (day 2 vs day 7): final HR, 152 $\pm$ 5 vs 130 $\pm$ 3 beats$\cdot$min^{-1} ($p<.025$); final Tre, 38.62 $\pm$ 0.11 vs 38.13 $\pm$ 0.07^{o}C ($p<.01$). Mean ($\pm$ SE) resting plasma volume expanded +10.1 $\pm$ 3.4 % by day 8. Mean sweat rate (490 $\pm$ 40 vs 530 $\pm$ 20 $g\cdot m^{-2}\cdot h^{-1}$), sweat sensitivity (370 $\pm$ 40 vs 470 $\pm$ 60 $g\cdot m^{-2}\cdot h^{-1}\cdot {}^{o}C$), and sweat sodium concentration (41 $\pm$ 4 vs 37 $\pm$ 6 $mEq\cdot L^{-1}$) were not significantly different (day 2 vs day 7). The lack of significant change in sweat rate is probably the result of a progressive decrease in the thermal stimulus for whole-body sweating (Tre). The observation that HR and Tre values respond to heat acclimation more rapidly than sweat measurements has been made during at least nine previous heat acclimation studies (Armstrong et al. 1985). These sweat values also agree with the observation of Wyndham et al. (1968) that sweat rate is not significantly increased until after 10 days of heat acclimation.

One subject (subject J) was defined heat intolerant, using the definition of Strydom (1980), which states that heat intolerance is the inability to adapt to work in the heat. This subject provided an interesting comparison to the other nine HP (above), because he was unable to adapt to exercise in a hot environment. His HR and Tre values, recorded at the end of daily 90min heat acclimation trials, were as follows (day 2 vs day 7): HR, 162 vs 168 beats$\cdot$min^{-1}; Tre, 39.00 vs 39.01^{o}C. The results of an identical 7-day heat acclimation protocol, conducted six months after the current investigation, demonstrated that subject J was still unable to acclimate to heat.

Table 2

The HTT composite scores (Eq. 1) for each subject on days 1 and 9 are compared to responses at the end of heat acclimation trials, in Table 2. The data for the lone heat intolerant HP (subject J) is separated from the nine other HP. The group mean composite score (n = 9) on day 1 was 39 $\pm$ 6, and on day 9 was 48 $\pm$ 6 ($p>.05$, NS).

Analysis of physiological measurements during HTT indicated that mean final HR and mean final Tre (day 1 vs day 9, Table 2) were not significantly different ($p>.05$, NS). Final HR and final Tre during HTT (days 1 and 9) were not significantly correlated ($p>.05$) with HR and Tre in the heat (days 2 and 7). In addition, ΔHR and ΔTre during HTT (days 1 and 9) were not significantly correlated ($p>.05$) with ΔHR and ΔTre in the heat (days 2 and 7). Similarly, no significant correlations existed between the change in HTT composite score (Table 2) and final HR, ΔHR, final Tre, or ΔTre in the heat (days 2 and 7).

A step-wise multiple linear regression equation was utilized to predict HTT composite score (Table 2) by using all HP physical characteristics (Table 1). The only significant independent variable was % body fat (r^2 = 0.57, $p<.05$) on day 1. Contrary to our previous findings in normal males (Armstrong et al.

1987), the VO_2max values of HP (Table 1) were not significantly correlated with HTT composite scores (Table 2). The authors believe that this was affected by differences in homogeneity of the subject samples.

Discussion

The initial description of HTT (Shvartz et al. 1977b) indicated that heat tolerance can be predicted accurately from HR and Tre responses during exercise in a temperate environment. Subsequently, the authors independently evaluated HTT by using 14 normal males (Armstrong et al. 1987) and reported that HTT did not accurately track HR or Tre responses observed in the heat, but that HTT may have value in HP or at-risk populations. The current investigation was designed to test the validity and sensitivity of HTT as a heat tolerance test for HP. The data were analyzed initially to answer the question, "Did HR and Tre during HTT track the HR and Tre responses observed during exercise in the heat?" When compared to heat acclimation trials of HP (40.1°C), the HTT composite scores (Table 2) resulted in three fallacious conclusions:

1. A composite score $\geq$ 75 points was originally defined as the score which indicated that subjects responded like heat acclimatized humans (Shvartz et al. 1977b). After 7 days of heat acclimation (day 9), only one out of 10 HP reached a composite score of $\geq$ 75 points (subject A). In addition, three HP had lower composite scores on HTT (subjects C, D and H) and one HP had the same score (subject J), after 7 days of heat acclimation (day 9).

2. Subject A exhibited the smallest decreases in final HR and final Tre as a result of heat acclimation (n = 9, day 2 vs day 7), yet exhibited the greatest improvement in HTT score (n = 9, day 1 vs day 9).

3. Subjects D and G experienced the greatest decreases in final HR and final Tre as a result of heat acclimation (n = 9, day 2 vs day 7), yet produced changes in HTT composite scores (n = 9, day 1 vs day 9) of -10 and +5, respectively (Table 2).

Therefore, these data demonstrated that HTT did not accurately track HR or Tre responses observed in the heat and, therefore, was not a sensitive or valid test of heat tolerance for HP. The following question also was of interest, "Did HTT identify heat intolerant individuals correctly?" In this regard, HTT composite scores resulted in three fallacious conclusions:

1. A composite score of 30 points or less was originally defined as the score which indicated heat intolerance (Shvartz et al. 1977b). Heat acclimation trials indicated that only subject J was heat intolerant (see results). HTT composite scores ($\leq$ 30 points) defined subjects B, E, G, and I heat intolerant on day 1, and subjects C and E heat intolerant on day 9.

2. Seven out of nine (78 %) HP had HTT composite scores which were equal to or less than subject J, the lone heat intolerant HP, on day 1. Four out of nine (44 %) HP scored less than subject J on day 9.

3. Because HP had been declared clinically normal prior to testing, and because HP exhibited successful heat acclimation responses (Table 2) they were defined heat tolerant. One would logically expect their composite scores to be

Figure 1 similar to normal males. However, Figure 1 illustrates that HTT scores of HP (39 $\pm$ 6 points) were clearly smaller than the previously reported HTT scores of 14 normal males (63 $\pm$ 5 points) (Armstrong et al. 1987).

Two additional considerations became evident during this testing. First, it appeared that the sample of subjects used to establish the original HR portion of the arbitrary composite scoring system (Table 3, Shvartz et al. 1977b) possessed high levels of cardiorespiratory physical fitness. Eight out of nine (89 %) HP in the current investigation completed the day 1 HTT with a HR score of only 10 to 20 points; the Tre portion of the HTT score (Eq. 1) invariably raised the composite score to the levels reported in Table 2. This suggests that the HTT composite score was highly population-specific. Second, bench stepping

is a bodily movement which involves muscular coordination and localized thigh fatigue. The authors believe that the exercise efficiency of this movement may improve with practice and with specific training of the quadriceps femoris muscle group.

Several physiological factors have been theoretically linked to heat intolerance, including: poor transfer of heat from the body's core to the skin (Shapiro et al. 1979), low body surface area-to-mass ratio and low work efficiency (Epstein et al. 1983), low sweat sensitivity (Burch 1956; Robinson et al. 1976), compromised cardiovascular function (Robinson et al. 1976), and low VO_2max (Shvartz et al. 1977b). Four of these factors were measured in the current investigation, and there were no statistically significant relationships ($p>.05$) between these four factors and HTT composite score. Because HTT does not involve thermal stress or prolonged exercise in the way that standardized heat tolerance tests do (Shapiro et al. 1979; Wyndham 1973), it does not address these physiological factors properly.

Although heat intolerant individuals may attain low composite scores on HTT (Shvartz et al. 1977b), scores on HTT do not always correctly indicate heat intolerance (i.e. subjects B, C, E, G, I, J). Even the original description of HTT (Shvartz et al. 1977b) reported that 5 out of 35 unacclimatized normal subjects scored $\leq$ 30 points on day 1 of HTT. Although a large sample of heat intolerant humans was not evaluated in either this investigation ($n = 1$) or the original work ($n = 4$), investigation of a large sample of heat intolerant individuals would be enlightening. The 3-5 % incidence of heat intolerance in the general population (Strydom 1980) indicates that such investigations will be difficult to organize in the future.

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TABLE 1 - SELECTED CHARACTERISTICS OF SUBJECTS

SUBJECT	AGE (yr)	HEIGHT (cm)	MASS (kg)	SURFACE AREA (m^2)	MASS / SURFACE AREA (kg/m^2)	% BODY FAT	$\dot{V}O_2$ max (ml/kg/min)
A	24	193	97.225	2.22	43.80	18.6	47.31
B	26	188	93.576	2.20	42.54	16.8	51.92
C	24	167	78.894	1.88	41.96	14.3	50.56
D	26	176	85.746	2.02	42.45	17.3	50.59
E	22	168	88.140	1.98	44.52	24.6	45.73
F	26	175	68.680	1.83	37.53	14.6	58.14
G	21	182	84.740	2.06	41.14	19.5	53.09
H	21	189	79.056	2.06	38.38	10.0	59.85
I	24	188	96.012	2.23	43.05	17.9	38.37
J	44	175	82.420	1.98	41.63	22.4	43.74
$\bar{x}$	26	181	85.449	2.05	41.69	17.6	49.93
$\pm$ SE	2	3	2.786	0.04	0.70	1.3	2.05

TABLE 2 - Comparison of HR (beats·min^{-1}) and Tre (^{o}C) after heat acclimation (days 2 and 7) and HTT (days 1 and 9). Composite scores are also given.

SUBJECT	HEAT ACCLIMATION TRIALS				TEMPERATE ENVIRONMENT HEAT TOLERANCE TEST (HTT)							COMMENTS
	FINAL HR [a]		FINAL Tre [a]		FINAL HR [b]		FINAL Tre [b]		COMPOSITE SCORE [c]			
	DAY 2	DAY 7	DAY 2	DAY 7	DAY 1	DAY 9	DAY 1	DAY 9	DAY 1	DAY 9	CHANGE	
A	139	128	38.19	38.00	166	137	37.8	37.7	45	80	+35	1,7
B	140	128	38.44	37.99	167	160	38.1	37.7	30	50	+20	7
C	143	119	38.29	38.07	178	170	37.9	38.0	35	30	-5	5
D	165	135	38.97	38.33	160	159	37.8	38.0	45	35	-10	3,4,5
E	158	142	39.01	38.42	176	187	38.7	38.0	10	30	+20	7
F	153	131	38.59	38.26	166	153	37.5	37.2	60	65	+5	
G	174	124	38.86	37.87	178	162	38.0	38.0	30	35	+5	3,4
H	129	118	38.36	37.90	134	133	37.8	37.9	65	60	-5	5
I	165	147	38.91	38.31	186	178	38.0	37.6	30	50	+20	4,7
$\bar{x}$	152	130	38.62	38.13	168	160	38.0	37.8	39	48	+9	
$\pm$ SE	5	* 3	0.11	** 0.07	5	6	0.1	0.1	6	6	5	
J [d]	162	168	39.00	39.01	193	170	37.7	37.7	45	45	0	2,6

[a] Measured at minute 90 of heat acclimation trials (40.1 $\pm$ 2.3^{o}C dry bulb)

[b] Measured at minute 15 of HTT trials (25.8 $\pm$ 0.4^{o}C dry bulb)

[c] See Eq. 1 in text

[d] Only subject J was defined heat intolerant (see results)

* $p < .025$

** $p < .01$

(continued)

TABLE 2 (continued from previous page)

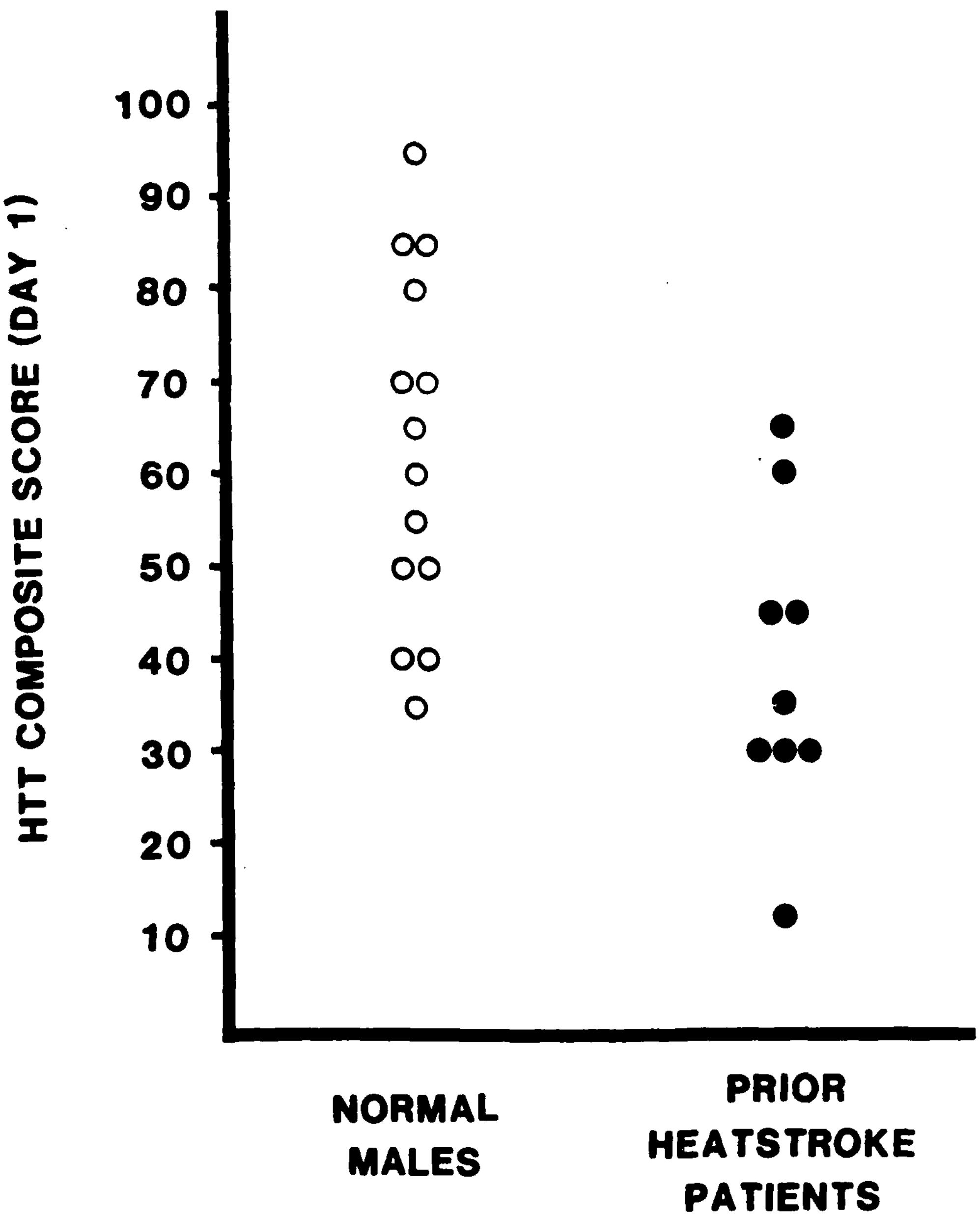
Comments

1. Exceeded 75 point composite score (indicating heat acclimatization) on day 9 of HTT, after 7 days of heat acclimation trials
2. No decrease in HR or Tre values in the heat resulted from 7 days of heat acclimation
3. Exhibited HR decrease of at least 30 beats$\cdot$min^{-1} in the heat (day 2 vs day 7)
4. Exhibited Tre decrease of at least 0.6^{o}C in the heat (day 2 vs day 7)
5. Composite score on HTT decreased after 7 days of heat acclimation
6. Composite score on HTT was unchanged after 7 days of heat acclimation
7. Composite score on HTT increased by 20 points or more after 7 days of heat acclimation

Figure Legend

Figure 1 – HTT composite scores of unacclimatized normal males and HP, prior to heat acclimation. Group mean (± SE) scores were 63 ± 5 and 39 ± 6, respectively. Data for normal males was originally reported by Armstrong et al. (1987).

Figure 1


HTT COMPOSITE SCORE (DAY 1)
100
90
80
70
60
50
40
30
20
10
NORMAL MALES
PRIOR HEATSTROKE PATIENTS